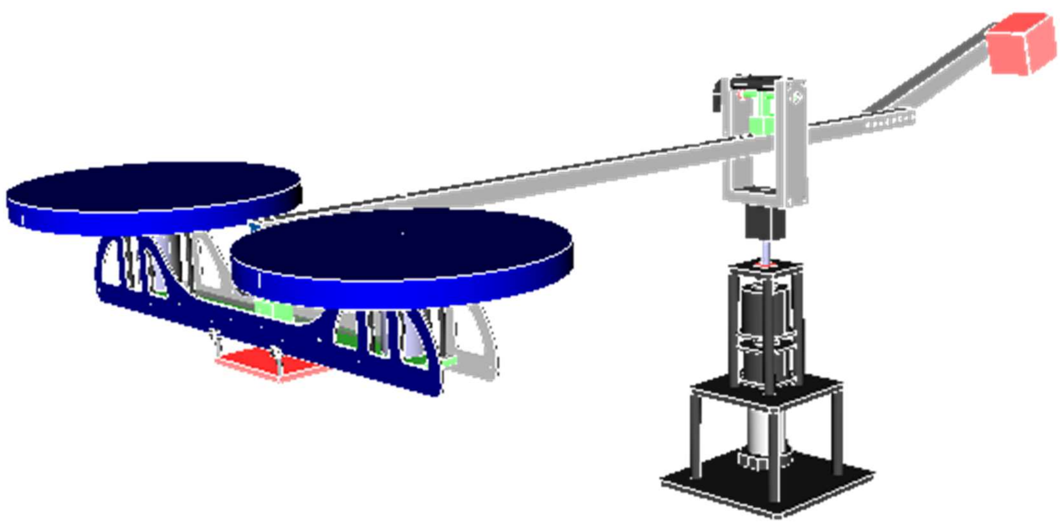
DEPARTMENT OF AEROSPACE ENGINEERING
FACULTY OF ENGINEERING, ARCHITECTURE AND SCIENCE

AER 715 AVIONICS AND SYSTEMS

Laboratory 5

Flight Control – Control System Testing and Analysis



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1. Instructions

- SAFETY FIRST – DO NOT PUT YOUR FINGERS OR ANY LOOSE ITEMS IN THE SERVOMOTOR GEARS.
- This lab is to be done **in groups of two (2)**.
- Download the lab manual, worksheet, and files from D2L and save them on the Desktop in a folder called LAB5.
- Read the instructions in the laboratory manual carefully and follow the specified procedures.
- Answer all questions in the provided worksheet.
- At the end of the lab, submit one lab worksheet along with the standard Ryerson Aerospace Assignment/Laboratory Cover Sheet. Each student must attend the laboratory and sign the Cover Sheet in order to receive a mark.

2. Flight Control – Control System Testing and Analysis

2.1 Introduction

In Lab 3 we developed a mathematical model for the elevation dynamics of the 3DOF Helicopter using analytical and experimental techniques. In Labs 4.1 and 4.2, we studied controller design and simulation for the helicopter. In this lab we take those designed controllers and test their performance on the real helicopter. You will also compare the performance of your controllers with a stock controller.

2.2 Purpose

The objective of this lab is to test your designed controllers on the real helicopter system and evaluate their performance against themselves and a stock controller.

2.3 Apparatus

To complete this lab, the following is required:

- Quanser 3-DOF Helicopter.
- Quanser UPM-2405 or VoltPAQ-X2 Power Module.
- Quanser Q4 data acquisition and control board.
- PC equipped with the necessary software.

2.4 Parameters of the 3-DOF Helicopter

The parameters of the 3-DoF helicopter are given in the following two tables:

Table 1: 3-DOF Weights and Measures

Symbol	MATLAB	Description	Unit	Value			
				Heli 1	Heli 2	Heli 3	Heli 4
M_h	Mh	Mass of Heli Body	[kg]	1.442	1.422	1.464	1.450
M_c	Mc	Mass of CW	[kg]	1.914	1.916	1.919	1.918
L_a	La	Distance from Pivot to Helicopter body centre	[in]	25.75			
L_b	Lb	Distance from Pivot to counterweight centre	[in]	18.125		18.5	
L_h	Lh	Distance from pitch axis to rotor center	[in]	6.985	6.932	6.995	6.933
J_e	Je	Moment of Inertia	[kg-m^2]	TBD	TBD	TBD	TBD
D_e	De	Viscous Damping	[N-m-s/rad]	TBD			
K_e	Ke	Spring Constant	[N-m/rad]	TBD			
F_t	Ft	Lift Force @ SLF	[N]	TBD	TBD	TBD	TBD

Table 2: Other Parameters and Limits of the 3-DOF Helicopter

Symbol	MATLAB	Description	Unit	Value			
				Heli 1	Heli 2	Heli 3	Heli 4
K_f	Kf	Motor-Prop Force Constant	[N/V]	0.140			
K_{rt}	Krt	Motor-Prop Torque Constant	[N.m/V]	0.0036	0.0032	0.0038	0.0027
ε		Elevation Range	[Degrees]	[~-26 to ~30]			
ε_o		Elevation Start	[Degrees]	-25.75			
λ		Travel Range	[Degrees]	0 to 360			
g	g	Gravity constant	[m/s^2]	9.81			
	KE_CNT	Encoder Resolution	[counts/rev]	-4096			
	KE_RAD	Encoder Resolution	[rad/count]	1.5340E-2			
	K_CABLE	Amplifier Gain	[V/V]	3		5	

3. Lab Work

3.1 Part A: Testing the Stock Controllers

<table>
<tr><th>STEP</th><th>DESCRIPTION/TASK</th></tr>
<tr><td>1</td><td>Download the files for Lab 5 from D2L and put them in a Lab5 folder on your desktop.</td></tr>
<tr><td>2</td><td>Start "<u>MATLAB</u>" and change the working directory to Lab5.</td></tr>
<tr><td>3</td><td>In Part A of the lab, you will run the helicopter using the stock controller that you will use to compare against your own developed controllers.

Open the "Heli_Setup.m" file and change the value of the <u>heli</u> to your specific helicopter and V_{sum} corresponding to the one from Lab 3. Also change the values of the PID gains provided to you by the GA for the stock controller. The stock controller gains have been tuned for the specific helicopter, though they may not be optimal.</td></tr>
<tr><td>4</td><td>Next, open up the file "<u>Heli_Controller_Testing.slx</u>" that you edited in Lab 4.1; it should look similar to the one shown in Figure 1 below and then change the HIL board# for your specific helicopter. Don't forget to change the gain values. For those who are conducting this lab remotely away from the lab, try to understand the model structure of the below diagram and jump to Step #8.

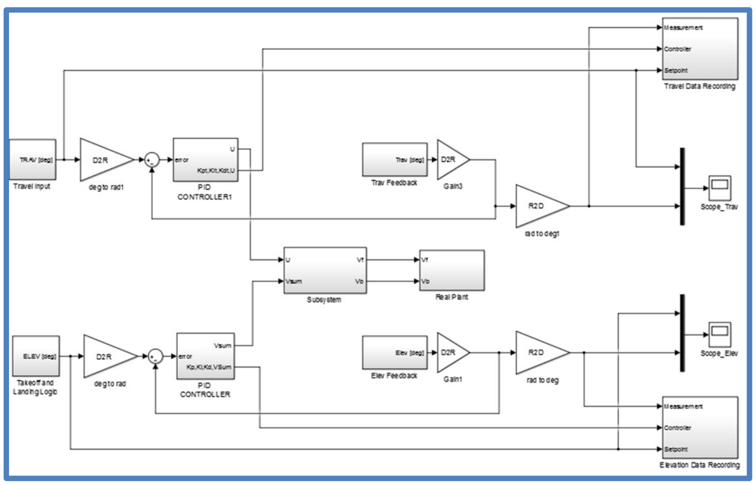
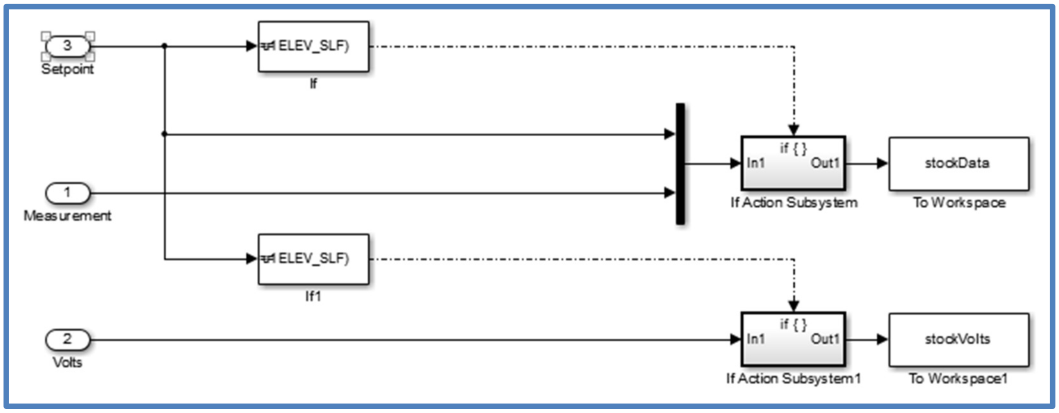


Figure 1 Simulink model for controller testing</td></tr>
<tr><td>5</td><td>In order for your radian-to-angle and angle-to-radian blocks to work properly, copy the files that you saved from Lab 4.1 into your working directory.</td></tr>
<tr><td>6</td><td>The data will be stored in the variables stockData and stockVolts in the Workspace. The variable stockVolts contains the controller voltage values for the controller gains (K_p, K_i, K_d) and V_{sum}. Save the data to a MATLAB file.</td></tr>
</table>

7	Change the data storage variables in the elevation data recording block (**To Workspace**) as shown in Figure 2. Change stockData to **elevData1** and stockVolts to **elevVolts1**.  **Figure 2 Variables in the Data Storage block.** Do the same for the travel data recording block (**To Workspace**) and rename the variables to **travData1** and **travVolts1** if it's not already been done so.
8	**For the virtual lab** (**Fall 2021 only**), you will be given the experimental data **elevData1** and **travData1**, which are downloadable from D2L. These data are recorded from the best available result with the following compensator (stock) gains: Kp = 45 Ki = 45 Kd = 28 Kpt = 98 Kit = 0 Kdt = 300 Compare the values of the gains you developed in Lab 4 with those provided above. Discuss with your partner, whether or not your gains make sense. Then, apply the above gain values to your simulation model in Lab 4 and compare the result with the experimental data (**elevData1** and **travData1**). What factors cause the discrepancies? **OR** **For the in-person lab** this semester (**Fall 2022**), you will be given the transfer functions of **G#_elev1** and **G#_trav** written within the **Heli_Setup.m** file of Lab 5. You have to use these functions and tune your PID compensator gains experimentally. You may use the stock gains given above as the baseline. After you have completed the experimental work, go back and use the provided **G#_elev1** and **G#_trav** to run your simulation model from Lab 4 again. Apply the PID compensator gains that you have obtained here in Lab 5 to the simulation model and observe the system response. Compare the result with the experimental data. What factors cause the discrepancies? (Hint: the way the simulation model is constructed vs the actual model of the helicopter control, and the limitation of SISOTOOL in compensator gains tuning)
9	Save all the variable data to MATLAB files and e-mail them for post processing.

3.2 Part B: Post Lab

STEP	DESCRIPTION/TASK

1	In a **<u>new</u>** script, type the following:
	
	`%-------------------------------------------`
	`% AER 715 Introduction to Avionics and Systems`
	`% Lab 5 – “Lab Title”`
	`% Your Full Name(s) & SID(s)`
	`%-------------------------------------------`
	`%`
	`%% Introduction`
	`%    Type your introduction in this section`
	`%`
	`%% Post Lab Exercises –`
	`%    Put your exercises in this section`
	`%`
	`%% Conclusion`
	`%    Write your lab conclusion for the WHOLE lab in this`
	`%    section.`
	`%`

2	Create a new section called Question 1 using the %% command. Create a comparison plot of the elevation data (**simulation result from Lab 4 with your best-tuned compensator gains vs simulation result from Lab 4 with the stock compensator gains vs experimental result here**). Use only the first 20 seconds of data. Also display the controller gain values in the script for each case. Compare and discuss the performance.
3	Repeat Step 2 for the data you collected from the travel test. **Use only the data between 25 second to 40 seconds marks.**